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### **PCT**

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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: IMPROVED CORED ELECTRODE WIRES

#### (57) Abstract

A cored electrode wire for pulsed electric arc welding, wherein said core includes from 2.5 to 12% calcium fluoride, from 2 to 8% calcium carbonate, from 0.2 to 2% silicon dioxide and from 0.5 to 1.5% of a fused mixed oxide. Also disclosed is a cored electrode wire for pulsed electric arc welding, wherein said core contains from 4 to 15% elemental manganese and from 2 to 8% elemental silicon, the remainder of the core comprising fused mixed oxide, desired alloying components and iron powder. In each of the above cases, the wire is suitable for use with the following welding pulse parameters: pulse energy: 8 to 250 J and preferably 10 to 120 J; pulse frequency: 10 to 500 Hz and preferably 15 to 350 Hz; background current: 8 to 250 A and preferably 10 to 100 A; wire feed speed: 1 to 20 m/min and preferably 4 to 17 m/min.

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#### TITLE: IMPROVED CORED ELECTRODE WIRES

#### Field of the Invention: 2

This invention relates to cored electrode wires for 3 pulsed electric arc welding and to a pulsed electric arc 4 welding method utilising same.

#### Background of the Invention: 6

Solid electrode wire generally suffers from lack of versatility in alloy composition, since only large batches are economical, and absence of the protective and cleaning 10 action provided by a slag. In addition, the solid wire/ 11 conventional power supply combination can give problems with lack of sidewall fusion in joining thicker sections.

Cored wires offer great versatility with regard to 13 14 alloy composition since alloy additions are made via the 15 core. They also generally give better sidewall fusion than solid wires. To reliably achieve the good low temperature 16 impact properties and low weld metal hydrogen levels 17 required in certain cases, basic-flux cored or metal cored 18 wires demonstrate considerable advantage compared to 19 alternative slag systems such as rutile ones. 20

However, the combination of basic cored wire with 21 conventional power supply gives harsh welding operation, can 22 be used only in a narrow range of welding currents, and is 23 not usable for positional welding. The combination of basic 24 cored wire with pulsed power supply, on the other hand, has 25 been found to give good welding behaviour over a wide range 26 of welding currents and to offer an all-position welding 27 capability. Similarly, metal cored wires are only usable at 28 high currents with conventional power supply but, when 29 combined with pulsed power supply give good welding 30 behaviour over a wide range of welding currents and offer 31 32 all-position welding capability.

#### 33 Summary of Invention and Objects:

It is therefore an object of a first aspect of the 34 present invention to provide cored electrode wires which are 35 suitable for use with pulsed electric arc welding programs, 36 and to provide a range of programmes suitable for use 37 38 therewith.

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In a first aspect, the invention provides a basic flux
 1
    cored electrode wire for pulsed electric arc welding,
    characterised in that the slag forming components contained
    in the core of said electrode wire are of a lower level than
    the slag forming components which must be contained in a
    basic flux cored wire suitable for normal arc welding.
         In a preferred form of the first aspect of the
    invention, the core includes from 2.5 to 12% calcium
    fluoride, from 2 to 8% calcium carbonate, from 0.2 to 2%
    silicon dioxide and from 0.5 to 1.5% of a fused mixed oxide.
10
         In a particularly preferred form of the invention, the
11
    core includes from 2.5 to 8% calcium fluoride, from 2 to 6\%
12
    calcium carbonate, from 0.2 to 1\% silicon dioxide and from
13
    0.75 to 1.25% fused mixed oxide. In one form, the fused
    mixed oxide may contain approximately 10% MgO, 15% MnO, 10%
16
    Al<sub>2</sub>O<sub>3</sub>, 5% CaO, 60% SiO<sub>2</sub>.
         The above defined electrode is suitable for pulsed arc
17
    welding with the following pulse parameters:
18
19
    Pulse Energy
                         8 to 250 J and preferably 10 to 120 J \,
20
    Pulse Frequency
                        10 to 500 Hz and preferably 15 to 350 Hz
    Background Current 8 to 250 A and preferably 10 to 100 A
21
22
    Wire Feed Speed
                        1 to 20 m/min and preferably 4 to 17 ^{\circ}
23
                        m/min
24
         In a presently preferred form of the invention, the
    core may have the following composition and is suitable for
25
   use with a pulsed electric arc welding program having the
26
27
    following pulse parameters:
28
   Wire Diameters 0.9 to 1.8 mm
29
   Shielding Gas Argon-carbon dioxide mixtures containing 2 to
30
   25\% CO_2 and, in some cases, up to 3\% O_2.
31
   Proportion of core - 15 to 28% of total wire weight may be
32
                          core
33
                        - preferably 18 to 25% of core
34
                        - specifically 23% core for 1.6mm dia
35 .
                          wires and 21% for 1.2mm dia wires.
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- 3 -

1	Core Composition		
2		Zage of	Core
3			Preferred
4		Broad Range	Range
5	Source of elemental Mn	3 to 12	5 to 9
6	(such as silicomanganese or		
7	manganese)	(as Mn)	
8	Source of elemental Si	2 to 7	2 to 5
9	(such as silicomanganese or		
10	ferrosilicon)	(as Si)	•
11	Calcium fluoride	2.5 to 12	2.5 to 8
12	(may be in mineral form)		
13	Calcium carbonate	2 to 8	2 to 6
14	(may be in mineral form)		
15	Silicon dioxide	0.2 to 2	0.2 to 1
16	(may be in mineral form,		
17	Fused mixed oxide	0.5 to 1.5	.75 to 1.25
18	(Containing approximately		
19	10% MgO, 15% MnO, 10% Al <sub>2</sub> O <sub>3</sub> ,	•	
20	5% CaO, 60% SiO <sub>2</sub> )		
21	Source of elemental Cr	0 to 1.5	depends on
22	(such as chromium or		alloy
23	ferrochromium)		required
24	Source of Ni	- 0 to 15	depends on
25	(such as nickel powder)		alloy
26			required
27	Source of Mo	0 to 5	depends on
28	(such as ferromolybdenum)		alloy
29			required
30	Source of Ti	0 to 1.5	0 to 0.8
31	(such as ferrotitanium)	(as Ti)	
32	Source of B	0 to .045	0 to .033
33	(such as ferroboron)	(as B)	
34	Iron powder	remainder	remainder
35	Pulse Parameters		Range
36	Pulse width (ms)		2 to 6
37	Peak current (A)		400 to 550
38	Minimum Pulse Frequency (Hz)		15 to 80

- 4 -

1		
	Maximum Pulse Frequency (Hz)	120 to 300
2	Minimum Background Current (A)	15 to 50
3	Maximum Background Current (A)	15 to 80
4	Minimum Wire Speed (m/min)	1.56 to 4.55
5	Maximum Wire Speed (m/min)	6.50 to 16.90
6	The specific combination of parameters	needs to be
7	optimized for each specific wire.	
8	In a second aspect, the invention provides	s a method of
9	operating a pulsed electric arc welding appar	ratus using a
10	cored electrode wire having a basic core	composition
11	comprising the steps of adjusting the param	eters of the
12	pulse program of the apparatus in accordan	ace with the
13	following:	•
14	Pulse Energy 8 to 250 J and preferably 1	
15	Pulse Frequency 10 to 500 Hz and preferably	y 15 to 350 Hz
16	Background Current 8 to 250 A and preferably 1	
17	Wire Feed Speed 1 to 20 m/min and prefera	bly 4 to 17
18	m/min	•
19	More specifically, the following param	eters may be
20	used:	•
21	Pulse Parameters	Range
22	Pulse width (ms)	
	·	2 to 6
23	Peak current (A)	2 to 6 400 to 550
	Peak current (A) Minimum Pulse Frequency (Hz)	
23 24 25	• •	400 to 550
23 24 25 26	Minimum Pulse Frequency (Hz)	400 to 550 15 to 80
23 24 25	Minimum Pulse Frequency (Hz) Maximum Pulse Frequency (Hz)	400 to 550 15 to 80 120 to 300
23 24 25 26	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)	400 to 550 15 to 80 120 to 300 15 to 50
23 24 25 26 27	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80
23 24 25 26 27 28	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  Maximum Wire Speed (m/min)	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90
23 24 25 26 27 28 29	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  Maximum Wire Speed (m/min)  In a particularly preferred form of this	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the
23 24 25 26 27 28 29 30	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  Maximum Wire Speed (m/min)  In a particularly preferred form of this core composition of the electrode wire is in access.	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with
23 24 25 26 27 28 29 30 31	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  Maximum Wire Speed (m/min)  In a particularly preferred form of this	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with
23 24 25 26 27 28 29 30 31 32	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  Maximum Wire Speed (m/min)  In a particularly preferred form of this core composition of the electrode wire is in act the definition of the first aspect of the appearing above.	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with e invention
23 24 25 26 27 28 29 30 31 32 33	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  Maximum Wire Speed (m/min)  In a particularly preferred form of this core composition of the electrode wire is in act the definition of the first aspect of the appearing above.  In a third aspect of the invention, the second control of the seco	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with e invention
23 24 25 26 27 28 29 30 31 32 33	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  In a particularly preferred form of this core composition of the electrode wire is in act the definition of the first aspect of the appearing above.  In a third aspect of the invention, the provides a cored electrode wire for use with pulse.	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with e invention the invention lised electric
23 24 25 26 27 28 29 30 31 32 33 34 35	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  In a particularly preferred form of this core composition of the electrode wire is in act the definition of the first aspect of the appearing above.  In a third aspect of the invention, the provides a cored electrode wire for use with pularc welding, characterised in that the core contents.	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with e invention lised electric tains a metal
23 24 25 26 27 28 29 30 31 32 33 34 35 36	Minimum Pulse Frequency (Hz)  Maximum Pulse Frequency (Hz)  Minimum Background Current (A)  Maximum Background Current (A)  Minimum Wire Speed (m/min)  In a particularly preferred form of this core composition of the electrode wire is in act the definition of the first aspect of the appearing above.  In a third aspect of the invention, the provides a cored electrode wire for use with pulse.	400 to 550 15 to 80 120 to 300 15 to 50 15 to 80 1.56 to 4.55 6.50 to 16.90 aspect, the cordance with e invention the invention dised electric tains a metal silicon than

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l electric arc welding. It will be appreciated that the inclusion of manganese 3 and silicon in a cored wire for use with normal electric arc 4 welding influences the running characteristics and bead 5 shape of the weld metal. If insufficient manganese and 6 silicon are included in the core, the bead shape will be 7 poor and the resulting weld will have inferior mechanical 8 properties. By using a cored wire in conjunction with a pulsed electric arc welding program, the present inventors 10 have found that less manganese and silicon may be included 11 in the core without adversely affecting the bead shape or running characteristics, thereby resulting in superior mechanical properties in the resultant weld. 13 14 In a preferred form of this aspect of the invention, 15 the core contains from 4 to 15%, and preferably 6 to 10% of elemental manganese and from 2 to 8% and preferably from 2.5 16 17 to 5% elemental silicon. The above electrode is suitable for pulsed arc. welding 18 19 with the following pulse parameters: 8 to 250 J and preferably 10 to 120 J 20 Pulse Energy 10 to 500 Hz and preferably 15 to 350 Hz 21 Pulse Frequency Background Current 8 to 250 A and preferably 10 to 100 A 1 to 20 m/min and preferably 4 to 17 23 Wire Feed Speed 24 m/min In a particularly preferred form of this aspect, the 25 core composition is as defined below and the pulse 26 parameters of the pulsed electric arc welding program 27 28 suitable for use with the cored wire are as follows: Wire Diameters 0.9. to 1.8 mm Shielding Gas Argon-carbon dioxide mixtures containing 2 to 30 25%  $CO_2$  and, in some cases, up to 3%  $O_2$ . 31 Proportion of core - 15 to 25% of total wire weight may be 32 33 - preferably 17 to 23% of core 34 - specifically 21% core for 1.6mm dia 35 wires and 1.2mm dia wires. 36 37



- 6 -

1	Core Composition		·
2		%age of	Core
3			Preferred
4		Broad Range	Range
5	Source of elemental Mn	4 to 12	6 to 10
6	(such as manganese powder or		
7	ferromanganese)	(as Mn)	
8	Source of elemental Si	2 to 8	2.5 to 5
9	(such as silicon powder or		
10	ferrosilicon)	(as Si)	
11	Source of Ti	0 to 1	0.2 to 0.5
12	(such as ferrotitanium)	(as Ti)	
13	Fused mixed oxide	0 to 1.5	0.2 to 1.0
14	(Containing approximately 10%	MgO,	
15	15% MnO, 10% Al <sub>2</sub> O <sub>3</sub> , 5% CaO,		
16	60% SiO <sub>2</sub> )		
17	Source of B	0 to 0.05	0.005 to .05
18	(such as ferroboron)	(as B)	(as B)
19	Source of elemental Cr	0 to 2	depends on
20	(such as chromium or		alloy
21	ferrochromium)		required
22			
23	Source of Ni	0 to 20	depends on
24	(such as nickel powder)		alloy
25			required
26	Source of Mo	0 to 5	depends on
27	(such as ferromolybenum		alloy
28			required
29	Iron powder	remainder	remainder
30	Pulse Parameters		Range
31	Pulse width (ms)		· 2 to 6
32	Peak current (A)		350 to 550
33	Minimum Pulse Frequency (Hz)		25 to 100
34	Maximum Pulse Frequency (Hz.		120 to 350
35	Minimum Background Current (A)		10 to 50
36	Maximum Background Current (A)		20 to 100
37	Minimum Wire Speed (m/min)		1.26 to 3.78
38	Maximum Wire Speed (m/min)		5.20 to 15.60

specific combination of parameters needs to be 1 optimized for each specific wire. In a fourth aspect of the present invention, there is 3 4 provided a method of pulsed electric arc welding utilising a 5 cored electrode wire containing a metallic core, 6 characterised in that the electric arc welding apparatus is 7 programmed with the following pulse parameters: 8 Pulse Energy 8 to 250 J and preferably 10 to 120 J 10 to 500 Hz and preferably 15 to 350 Hz 9 Pulse Frequency 10 Background Current 8 to 250 A and preferably 10 to 100 A 11 Wire Feed Speed 1 to 20 m/min and preferably 4 to 17 12 m/min More specifically, the following parameters may be 13 14 used: 15 Pulse Parameters Range 2 to 6 16 Pulse width (ms) 350 to 550 17 Peak current (A) 25 to 100 18 Minimum Pulse Frequency (Hz) 120 to 350 19 Maximum Pulse Frequency (Hz) 10 to 50 20 Minimum Background Current (A) 20 to 100 21 Maximum Background Current (A) 1.26 to 3.78 22 Minimum Wire Speed (m/min) 5.20 to 15.60 23 Maximum Wire Speed (m/min) Brief Description of the Drawings: 24 Figure 1 is a graph showing the variation of deposition 25 26 rate with welding current for a basic cored wire/pulsed welding process embodying the invention compared to that 27 28 normally obtained from a non-pulsed commercially available 29 basic cored wire; Figure 2 is a graphical summary of yield strength and 30 Charpy impact results obtained from wires embodying the 31 32 invention: Figure 3 is a graph showing the variation of deposition 33 34 rate with welding current for a metal cored wire/pulsed welding process embodying th invention compared with a 35 36 conventional metal cored wire using non-pulsed welding. <u>Description of Preferred Embodiments:</u> 37

Several preferred embodiments of each of the above

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1 aspects of the invention will now be described in greater 2 detail. The examples of preferred embodiments of the basic cored electrode wire resulted from substantial experimentation.

The welding power supply used was a Welding Industries 5 of Australia CDT Pulse Welder. A personal computer was attached, via a serial link, to the pulse program storage 7 8 area of the power supply controls. This allowed any of the ten pulse parameters in the pulse programme being used to be altered at will. A commercial package would include supply 10 of an EPROM for installation into the CDT pulse welder or 11 12 other pulse welder, with the optimum pulse program for a 13 specific wire.

Example 1 - Basic wire-pulse combinations for joining HY80 14 15 steel.

16 One of the early experimental wires of 1.6mm diameter was chosen and an exercise undertaken to find a combination 17 of pulse parameters which gave optimum operating behaviour 18 over a wide current range. This resulted in a pulse program 19 20 which gave good welding behaviour, a flat to slightly convex fillet shape and very little spatter over the welding 21 current range 130 to 350A. Furthermore, the lower end of 22 this range (about 130 to 150A) could be used for positional 23 welding with slightly convex but acceptable vertical and 24 overhead stringer beads being achievable. Weave techniques 25 26 allowed the production of good profile positional fillet 27 welds.

28 Measurements were made of the variation of deposition 29 rate and efficiency with welding current using a 30 representative wire and pulse program. The deposition rate results, together with those obtained previously for a 31 commercially available basic flux cored wire under steady 32 current conditions are given in Fig. 1. These show that 33 higher deposition rates at given current occur under pulsed 34 conditions and that the process under development can give 35 36 deposition rates of up to 7 kg of weld metal/hour at usable 37 welding current. The deposition efficiency of the experimental wire was 95 to 97% across the current range.

It should be noted that the Fig. 1 graph of deposition 2 rate against cement applies to any 1.6 mm diameter basic 3 wire embodying the invention under pulse conditions.

A series of experimental wires were formulated to investigate the influence of alloying additions, principally 6 Mn, Ni, Mo, Ti and B, on the all-weld-metal mechanical properties. The Table below gives the nominal deposit compositions aimed for, and classifies the wires according to the general approach used. The weld metal from all wires

10 contained approximately 0.06%C and 0.3 to 0.4% Si.
11 Wire General Nominal Composition (wt %)

11	MILE	961	ne.	41				<del>ИОШТ</del>	<u>.na1 9</u>	Omposi	7	WC 707	
12	No.	<u>C1</u>	ass	3				Mn	<u>Ni</u>	<u>Mo</u>	<u>Ti</u>	<u>B</u>	<u>Other</u>
13	1	Not	t i	nic	roal:	Lo	yed	1.5	1.6	0.25	-	-	
14	2	tt			11			1.2	1.6	0.25	-	_	
15	3	17			11			1.5	2.2	0.25	-	-	
16	4	tt			11			1.2	2.2	0.25	-	_	
17	5	11			11			1.0	3.0	0.25	-	-	•
18	6	Ti	ad	idit	tion			1.5	1.6	0.25	0.04	_	
19	7	11		11				1.2	1.6	0.25	0.04	-	
20	8	11		11				1.2	2.2	0.25	0.04	-	
21	9	11		11				1.0	3.0	0.25	0.04	-	
22	10	Ti	+	25	ppm	В		1.5	1.6	0.25	0.04	.0025	
23	11	11			tt	71		1.2	1.6	0.25	0.04	.0025	
24	12	11			***	***		1.2	2.2	0.25	0.04	.0025	
25	13	11			tt	**		1.0	3.0	0.25	0.04	.0025	
26	14	Ti	+	50	ppm	В		1.5	1.6	0.25	0.04	.005	
27	15	11		•	Ħ	**		1.2	1.6	0.20	0.04	.005	
28	16	11			11	11		1.2	2.2	0.25	0.04	.005	
29	17	11			***	**		1.0	3.0	0.25	0.04	.005	
30	18	Ti	+	50	ppm	В	no Mo	1.5	1.6	-	0.04	.005	
31	19	11			***	**	***	1.2	1.6	-	0.04	.005	
32	20	11			11	11	11	1.2	1.6	<b>-</b> .	0.04	.005	.01 A1
33	21	11			Ħ	**	71	1.2	1.6	_	0.04	.005	.02 A1
34	22	11			77	11	***	1.2	1.6	-	0.04	.005	
35	23	11			11	**	71	1.0	3.0	_	0.04	.005	

Test plates were welded from each of these wires using the pulse program developed. The parent plate was C-Mn steel (250 Grade) of 19mm thickness while the joint preparation 1 and interpass temperature were as specified by the American

2 Welding Society (ANSI/AWS A5. 20-79, 1978) for all-weld test

3 plates. Welding was done in the flat position with

mechanized travel and a heat input of 1.7 kJ/mm. One all-

5 weld-metal tensile test specimen (50mm gauge length) and

6 three to five Charpy V-notch impact specimens were taken

7 from each test plate. Charpy testing was done at -51 °C.

Figure 2 is a schematic representation of the impact 8 and tensile results obtained using the wire numbers from the 9 table. Also marked on this figure are the minimum Charpy 10 values specified and the range of yield strength values 11 specified. This figure illustrates several important 12 features of the results. It is apparent that premium Charpy 13 results, of above say 100J at  $-51^{\circ}C$ , were only obtained with wires microalloyed with Ti and 50 ppm B. These premium 15 Charpy results could be obtained using two distinct Mn-Ni 16 combinations: 1.2% Mn - 1.6% Ni with additions of 0.2% Mo or 17 0.02% of A1 (wires 15 and 21); or 1.0% Mn-3.0% of Ni with 18 19 no further addition (wire 23).

The yield strength results show that, of the wires giving premium Charpy values, wires 21 and 23 are within the range specified while wire 15 is marginally too high. Wires 15 and 23 gave 22% tensile elongation while wire 21 gave 24 26%.

Diffusible hydrogen in weld metal from these wires was found to be 2 to 3 m1/100g of weld metal using the IIW procedure and a gas chromatography measuring system.

Metallographic examination revealed that the as-welded microstructure from wires giving premium impact properties contained at least 90% of fine grained constituents nucleated within prior austenite grains, such as acicular ferrite and intragranular polygonal ferrite.

Based on the all-weld-metal results described above wires 15, 18, 21 and 23 were selected for further assessment. Flat position test plates were welded from 16mm thick HY80 steel using the "groov weld metal test" geometry described in U.S. Military Specification MIL-E-24403/2A (SH), 1983. Heat input was approximately 1.7 kJ/mm. From

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these test plates one all-weld tensile specimen, ten Charpy specimens and three dynamic tear specimens were machined. Half of the Charpy specimens were tested at  $-18^{\circ}$ C and half at  $-51^{\circ}$ C while the dynamic tear tests were done at  $-29^{\circ}$ C.

5 The table below lists the average values of the results.

6		Tensil	<u>e</u>	<u>Charpy V</u>	-notch	<u>Dynamic</u> <u>Tear</u>
7	Wire No.	<u>Yield</u>	<b>Elongation</b>	<u>Av at -18</u>	<u>Av at -51°C</u>	Av at -29°C
8		(MPa)	(%)	<b>(</b> J)	<b>(</b> J)	(J)
9	15	687	24	92	50	419
10	18	673	22	118	64	584
11	21	664	23	120	74	528
12	23	638	23	113	87	676

The yield strengths are considerably increased, by between 35 and 90 MPa, compared to the all-weld-metal results. This is due to incorporation in the weld of alloying elements from the parent plate and, as a result, wires 15, 18 and 21 (marginally) give yield strength values which are too high. Wire 23 has yield strength and elongation properties meeting the requirements of the U.S. Military Specification referred to above. All wires meet the dynamic tear requirements of the U.S. Military Specification.

Overall therefore wire 23, which gives a nominal weld metal composition of 1% Mn, 3% Ni plus microalloying additions of Ti and B, gives welds in HY80 steel having the best strength, elongation and impact properties.

The core composition and specific pulse parameters used for wire 23 are listed below:

29	Core Composition	% by weight
30	Iron powder	64.6
31	Manganese powder	4.1
32	Ferrosilicon	4.1
33	Fluorspar	5.3
34	Marble	4.1
35	Silica	0.4
36	Fused mixed oxide	1.0
37	Nickel powder	13.0
38	Ferrotitanium	1.0

	- 12 -	
1	Iron/Ferroboron agglomerate	2.4
2	Pulse parameters	_,,
3	Pulse width	3.5 ms
4	Peak current	520A
5	Minimum frequency	40 Hz
6	Maximum frequency	160 Hz
7	Minimum background current	35≜
8	Maximum background current	35▲
9	Minimum wire speed (m/min)	2.08
10	Maximum wire speed (m/min)	9.10
11	It will be appreciated tha	at any combination of pulse
12	parameters which achieve the mo	re general pulse parameters
13	defined above will be satisfa	ctory and will be open to
14	selection by an experienced oper	ator.
15	The following examples of	preferred basic flux wires
16	for joining normal structural sta	eels resulted from the above
17	tests and further experimentatio	n:
18		•
19	Wire of 1.6mm diameter with	23% fill for joining normal
20	structural grade steels using Ar	gon - 18% CO <sub>2</sub> shielding gas.
21	(Wire 244, Test plate MI)	-
22	Core Composition	% by weight
23	Iron powder	76.8
24	Silico manganese	9.8
25	Ferrosilicon	2.6
26	Fluorspar	5.3
27	Marble	4.1
28	Silica	0.4
29	Fused mixed oxide	1.0
30	Pulse parameters	
31	Pulse width	4.8 ms
32	Peak current	500A
33	Minimum frequency	37.8 Hz
34	Maximum frequency	132 Hz
35	Minimum background current	34A
36	Maximum background current	40A
37	Minimum wire speed $(m/min)$	2.47
38	Wa-d-	_ · · ·

Maximum wire speed (m/min)

7.80

```
1 Operation
 2 Gives good operation and bead shape over entire range for
 3 flat and horizontal welding positions and gives all-position
 4 welding capability at low wire feed speeds.
5 Weld Metal
 6 Composition (wt %)
                        С
                             0.09
 7
                        Mn 1.24
                         Si 0.41
 8
         Tensile properties 560 MPa tensile strength, 30%
 9
                              elongation
10
                              average of 128J at -20°C in Charpy
         Impact properties
11
                              test
12
13
         Diffusible hydrogen less than 3 ml/100g
14
    Example 3
         Wire of 1.2mm diameter with 21% fill for joining normal
15
    structural grade steels using Argon - 18% \mathrm{CO}_2 shielding gas.
16
    (Wire 244/9, test plate PT).
17
                                       % by weight
         Core Composition
18
                                          74.2
19
         Iron powder
                                          10.9
20
         Siliso manganese
                                           2.9
21
         Ferrosilicon
                                           5.9
         Fluorspar
22
                                           4.6
23
         Marble
                                           0.4
24
         Silica
                                           1.1
25
         Fused mixed oxide
         Pulse parameters
26
27
         Pulse width
                                                  2.5 ms
                                                    480A
28
         Peak current
                                                   75 Hz
29
         Minimum frequency
                                                  206 Hz
30
         Maximum frequency
31
         Minimum background current
                                                     25A
                                                      25A
32
         Maximum background current
33
         Minimum wire speed (m/min)
                                                    4.42
                                                   11.83
         Maximum wire speed (m/min)
34
35 Operation
```

- 36 Gives good operation and bead shape over entire range for
- flat and horizontal welding positions and gives all-position 37
- 38 welding at low and intermediat wire speeds.



```
1 Weld Metal
    Composition (wt %)
                         С
                              .09
 3
                             1.40
                         Mn
 4
                         Si 0.43
         Tensile properties 605 MPa tensile strength, 25%
 5
 6
                              elongation
 7
         Impact properties
                              average of 116J at -20°C in Charpy
 8
                              test
 9
         Diffusible hydrogen less than 3 ml/100g
    Example 4 - Pulsed Basic Wire for High Strength Steel.
10
         Wire of 1.6 mm diameter with 23% fill to American
11
    Welding Society classification E111T5-K4 for joining high
12
    strength steels and using Argon - 18% {
m CO}_2 shielding gas
13
    (Wire 2106, test plate SN).
14
15
         Core Composition
                                        % by weight
16
         Iron Powder
                                            60.7
17
         Manganese powder.
                                             6.7
18
         Ferrosilicon
                                             4.5
19
         Fluorspar
                                             5.3
20
         Marble
                                             4.1
21
         Silica
                                             0.4
22
         Fused mixed oxide
                                             1.0
23
         Ferrochromium
                                             0.9
24
         Nickel powder
                                            10.4
25
         Ferromolybdenum
                                             2.1
26
         Ferrotitanium
                                             1.5
27
         Iron/Ferroboron agglomerate
                                             2.4
28
         Pulse parameters
29
         Pulse width
                                                        4.8 ms
30
         Peak current
                                                          475A
31
         Minimum frequency
                                                       37.8 Hz
32
         Maximum frequency
                                                        165 Hz
33
         Minimum background current
                                                           45A
34
         Maximum background current
                                                           45A
35
         Minimum wire speed (m/min)
                                                          2.39
36
         Maximum wire speed (m/min)
                                                          8.06
37
    Operation 9 4 1
    Gives good operation and bead shape over entire range for
```

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35 36

1 flat and horizontal welding positions and gives all-position

2 welding capability at low wire feed speeds.

3 Weld Metal

Composition (wt %) 0.06% C, 1.49% Mn, 0.39% Si, 2.39% Ni, 4 5

0.30% Cr, 0.35% Mo, 0.04% Ti, 0.0066% B.

6 Tensile properties 711 MPa yield strength,

809 MPa tensile strength,

8 20% elongation.

> average of 47J at -51°C in Charpy Impact properties test

Diffusible hydrogen less than 3 ml/100g 11

The results show that the combination of basic-flux cored wires and specifically programmed pulse welding provides a versatile welding process with enhanced usability. High deposition downhand welding and an allposition capability can be achieved with a single pulse program by altering the wire feed speed and hence the 18 welding current. Furthermore, the impact and tensile properties obtained from the alloy combination of wire 23 when using this process meet or exceed the requirements of joining HY80 steel. The requirement on diffusible hydrogen level is also readily met.

These results suggest that this combination should be suitable for all-position joining of such steels and of offering considerable advantages over presently available processes.

The principal advantage of the above embodiments compared to conventional basic wire welding is in the improved operating behaviour and bead shape. The basic wirepulse welding combination allows a much wider range of average welding currents to be used and makes all-position welding with basic wires practical. An example of the extended current range achieved is that, for a 1.6 mm diameter basic wire and pulse welding this range is 130 to 350A whereas, with convention welding the range is 230 to 300A.

37 This advantage is illustrated in the following example of a test-plate welded in the vertical position using pulse 38

- 1 welding, it being appreciated that it is not practical to
- 2 produce such a test-plate by conventional means.
- 3 Example 5
- Wire of 1.2 mm diameter with 21% fill for joining 4
- 5 normal structural grade steels using Ar. 18%  ${
  m CO}_2$  shielding
- gas (wire 244/9, test-plate LB63.
- 7 Core Composition and Pulse Parameters (as in Example 3).
- 8 Operation
- 9 Good vertical position welding operation illustrated by fact
- 10 that sound Vee-butt test plate produced to Lloyds Register
- of Shipping "Approval of Welding Consumables" requirements. 11
- 12 Weld
- 13 Composition (wt %) С .07 14
- Mn1.38 15 Si .51
- 16 Impact Properties average of 96 J at -20°C in
- 17 Charpy test
- Transverse tensile test met requirements of Lloyds 18 19 Register of Shipping.
- Face and Root bend tests met requirements of Lloyds 20
- 21 Register of Shipping.
- In addition to the above described advantages, the 22
- basic cored wires contain significantly less slag forming 23
- components in the core thereby resulting in less troublesome
- welding performance while maintaining the necessary quality 25
- 26 of the weld.
- Tests similar to the above were conducted in relation 27
- 28 to various metal cored wires, and the following examples of
- 29 preferred embodiments resulted:
- 30 Examples Metal Cored Wires
- Example 6 Wire of 1.6mm diameter with 21% fill for joining 31
- normal structural grade steels using Argon 18%  $CO_2$ 32
- shielding gas. (Wire 345, Test plate NA).

34	Core Composition	% by weight
35	Iron powder	83.2

36 Manganese powder 7.3

37 Ferrosilicon 4.4 38 Silicon powder

1.3

- 17 - .

<b>7</b>	
•	
in the state of th	
· · · · · · · · · · · · · · · · · · ·	
Maximum wire speed (m/min) 8.45	
<u>Operation</u>	
Very good operation and bead shape over entire range for	r
flat and horizontal welding positions. Has all-position	n
welding capability at lower wire feed speeds.	
Weld Metal	
Composition (wt %) 0.05C, 1.31 Mn, 0.62Si, 0.04 Ti,	
0.0065 B	
Tensile properties 598 MPa tensile stength,	
24% elongation	
Impact properties average of 109J at -20°C in Charpy	7
test	
Example 7 - Wire of 1.2mm diameter with 21% fill for joining	ıg
normal structural grade steels using Argon - 18% CO	2
shielding gas. (Wire 345, Test plate OX).	
<pre>Core Composition</pre> <pre>% by weight</pre>	
Iron powder 83.5	
Manganese powder 7.3	
Ferrosilicon 4.4	
Silicon powder 1.3	
Ferrotitanium 0.8	
Fused mixed oxide 0.4	
Ferroboron/iron powder agglomerate 2.6	
Pulse parameters	
Pulse width 2.6 ms	
Pulse width 2.6 ms Peak current 400A	
	Minimum background current  Maximum background current  Minimum wire speed (m/min)  Maximum wire speed (m/min)  Operation  Very good operation and bead shape over entire range for flat and horizontal welding positions. Has all-position welding capability at lower wire feed speeds.  Weld Metal  Composition (wt %) 0.05C, 1.31 Mn, 0.62Si, 0.04 Ti, 0.0065 B  Tensile properties 598 MPa tensile stength, 24% elongation  Impact properties average of 109J at -20°C in Charpy test  Example 7 - Wire of 1.2mm diameter with 21% fill for joining normal structural grade steels using Argon - 18% CC shielding gas. (Wire 345, Test plate 0%).  Core Composition % by weight  Iron powder 83.5  Manganese powder 7.3  Ferrosilicon 4.4  Silicon powder 1.3  Ferrotitanium 0.8  Fused mixed oxide 0.4  Ferroboron/iron powder agglomerate 2.6

Maximum frequency  Minimum background current  Maximum background current  Maximum background current  Minimum wire speed (m/min)  Maximum wire speed (m/min)  Minimum wire speed (m/min)  Maximum wire speed (m/min)  Maximum wire speed (m/min)  Maximum wire speed (m/min)  Maximum background current  Maximum background current  Maximum background current  Minimum background current  Minimum background current  Maximum background in 1.95  Maximum bac
Maximum background current  Minimum wire speed (m/min)  Maximum wire speed (m/min)  Noperation  Very good operation and bead shape over entire range for flat and horizontal welding positions plus very good all-position welding capability at low and intermediate wire feed speeds.  Metal Metal  Composition (wt %)  Maximum background current  Minimum  Minimum wire speed (m/min)  Noperation  Noperation  Noperation  Maximum background current  Noperation  Nop
Minimum wire speed (m/min)  Maximum wire speed (m/min)  Maximum wire speed (m/min)  Operation  Very good operation and bead shape over entire range for flat and horizontal welding positions plus very good all-position welding capability at low and intermediate wire feed speeds.  Meld Metal  Composition (wt %)  O.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti,  O.0055% B  Tensile properties 589 MPa tensile strength,  23% elongation  Impact properties average of 123J at -20°C in Charpy test  There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
Maximum wire speed (m/min)  1.95  Maximum wire speed (m/min)  7 Very good operation and bead shape over entire range for flat and horizontal welding positions plus very good all-position welding capability at low and intermediate wire feed speeds.  11 Weld Metal  12 Composition (wt %)  13 0.0055% B  14 Tensile properties 589 MPa tensile strength,  15 23% elongation  16 Impact properties average of 123J at -20°C in Charpy test  18 There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
Operation Very good operation and bead shape over entire range for flat and horizontal welding positions plus very good all-position welding capability at low and intermediate wire feed speeds.  Weld Metal Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti, 0.0055% B Tensile properties 589 MPa tensile strength, 23% elongation Impact properties average of 123J at -20°C in Charpy test There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
Very good operation and bead shape over entire range for flat and horizontal welding positions plus very good all-position welding capability at low and intermediate wire feed speeds.  11 Weld Metal 12 Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti, 0.0055% B 14 Tensile properties 589 MPa tensile strength, 23% elongation 16 Impact properties average of 123J at -20°C in Charpy test 18 There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
position welding capability at low and intermediate wire feed speeds.  Weld Metal Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti, 0.0055% B Tensile properties 589 MPa tensile strength, 23% elongation Impact properties average of 123J at -20°C in Charpy test There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
position welding capability at low and intermediate wire feed speeds.  11 Weld Metal 12 Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti, 0.0055% B 14 Tensile properties 589 MPa tensile strength, 23% elongation 16 Impact properties average of 123J at -20°C in Charpy test 18 There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
Weld Metal  Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti,  0.0055% B  Tensile properties 589 MPa tensile strength,  23% elongation  Impact properties average of 123J at -20°C in Charpy  test  There are two principal advantages of using the above  metal cored wires with pulsed welding compared to  conventional welding with metal cored wire. Firstly, in  common with the above basic wires, the range of usable  welding currents is much wider so that all-position welding  becomes practical at the lower currents. With 1.6 mm  diameter metal cored wire and pulsed welding for example the  range of average current that is usable is 120 to 350 A
11 Weld Metal  12 Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti,  13 0.0055% B  14 Tensile properties 589 MPa tensile strength,  15 23% elongation  16 Impact properties average of 123J at -20°C in Charpy  17 test  18 There are two principal advantages of using the above  19 metal cored wires with pulsed welding compared to  20 conventional welding with metal cored wire. Firstly, in  21 common with the above basic wires, the range of usable  22 welding currents is much wider so that all-position welding  23 becomes practical at the lower currents. With 1.6 mm  24 diameter metal cored wire and pulsed welding for example the  25 range of average current that is usable is 120 to 350 A
Composition (wt %) 0.06% C, 1.49% Mn, 0.62 Si, 0.04 % Ti,  0.0055% B  Tensile properties 589 MPa tensile strength,  23% elongation  Impact properties average of 123J at -20°C in Charpy  test  There are two principal advantages of using the above  metal cored wires with pulsed welding compared to  conventional welding with metal cored wire. Firstly, in  common with the above basic wires, the range of usable  welding currents is much wider so that all-position welding  becomes practical at the lower currents. With 1.6 mm  diameter metal cored wire and pulsed welding for example the  range of average current that is usable is 120 to 350 A
O.0055% B  Tensile properties 589 MPa tensile strength, 23% elongation  Impact properties average of 123J at -20°C in Charpy test  There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
Tensile properties 589 MPa tensile strength,  23% elongation  Impact properties average of 123J at -20°C in Charpy  test  There are two principal advantages of using the above  metal cored wires with pulsed welding compared to  conventional welding with metal cored wire. Firstly, in  common with the above basic wires, the range of usable  welding currents is much wider so that all-position welding  becomes practical at the lower currents. With 1.6 mm  diameter metal cored wire and pulsed welding for example the  range of average current that is usable is 120 to 350 A
15 23% elongation 16 Impact properties average of 123J at -20°C in Charpy 17 test 18 There are two principal advantages of using the above 19 metal cored wires with pulsed welding compared to 20 conventional welding with metal cored wire. Firstly, in 21 common with the above basic wires, the range of usable 22 welding currents is much wider so that all-position welding 23 becomes practical at the lower currents. With 1.6 mm 24 diameter metal cored wire and pulsed welding for example the 25 range of average current that is usable is 120 to 350 A
Impact properties average of 123J at -20°C in Charpy test  There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
There are two principal advantages of using the above metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
metal cored wires with pulsed welding compared to conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
conventional welding with metal cored wire. Firstly, in common with the above basic wires, the range of usable welding currents is much wider so that all-position welding becomes practical at the lower currents. With 1.6 mm diameter metal cored wire and pulsed welding for example the range of average current that is usable is 120 to 350 A
21 common with the above basic wires, the range of usable 22 welding currents is much wider so that all-position welding 23 becomes practical at the lower currents. With 1.6 mm 24 diameter metal cored wire and pulsed welding for example the 25 range of average current that is usable is 120 to 350 A
22 welding currents is much wider so that all-position welding 23 becomes practical at the lower currents. With 1.6 mm 24 diameter metal cored wire and pulsed welding for example the 25 range of average current that is usable is 120 to 350 A
23 becomes practical at the lower currents. With 1.6 mm 24 diameter metal cored wire and pulsed welding for example the 25 range of average current that is usable is 120 to 350 A
24 diameter metal cored wire and pulsed welding for example the 25 range of average current that is usable is 120 to 350 A
25 range of average current that is usable is 120 to 350 A
26 while, with conventional welding it is 280 to 340A. This
27 could be illustrated using an example, along similar lines
28 to that above for the basic wire, of results from a vertical
29 weld.
The second principal advantage concerns the improved
31 weld mechanical properties obtained. This difference between
32 pulse and conventional metal cored wires is illustrated by
33 the following:
34 Wire Number 328 345 )see Example
35 Welding Method
36
details  Test plate type all weld metal all weld metal
38

1	Weld Composition (wt%)		
2	С	0.04	0.05
3	Mn	1.60	1.31
4	Si	1.04	0.62
5	Weld Properties		•
6	Impact (CVN at -20°C)	64 J	109 J
7	Tensile Strength	622 MPa	598 MPa
8	Tensil Elongation	23%	24%
9	The difference in	impact propert	ies is most important
10	because it allows the	wire/pulse comb	ination to be used in
11	more critical applicati	ons. In addition	n to these advantages,
12	the amounts of mangane	se and silicon	are reduced, thereby
13	improving the mechanic	al properties	of the weld, without
14	compromising the running	ng characterist	ics and bead shape of
15	the weld.		
16	Example 8 - Pulsed Meta		
17			21% fill to American
18	Welding Society class:		
19	strength steels and usi	ng Argon - 18% (	CO <sub>2</sub> shielding gas (Wire
20	359, test plate UH).		
21	Core Composition	2	by weight
22	Iron powder		65.5
23	Manganese powder		9.6
24	Ferrosilicon		3.8
25	Ferrotitanium		0.8
26	Silicon powder		1.1
27	Fused mixed oxide		0.4
28	Iron/Ferroboron ag	glomerate	2.6
29	Nickel powder		12.7
30	Ferromolybdenum	,	3.5
31	Pulse parameters		
32	Pulse width		5.2 ms
33	Peak current		460A
34	Minimum frequency		38 Hz
35	Maximum frequency		152 Hz
36	Minimum background	current	40A
37	Maximum background		40A
38	Minimum wire speed	(m/min)	2.39

- 20 -

_	Harrman Arie Sheed (H/HIH) 1.20
2	<u>Operation</u>
3	Very good operation and bead shape over entire range for
4	flat and horizontal welding positions. Has all-position
5	welding capability at lower wire feed speeds.
6	Weld Metal
7	Composition (wt %) 0.05% C, 1.49% Mn, 0.40% Si, 2.6% Ni
8	0.12% Cr, 0.56% Mo, 0.04% Ti, 0.005% B
9	Tensile properties 686 MPa yield strength,
10	797 MPa tensile strength,
11	24% elongation.
12	Impact properties average of 41J at -18°C in Charpy
13	test
14	Diffusible hydrogen 2 to 4 $m1/100g$
15	It will be appreciated from the above that the improved
16	cored electrode wires enable pulsed electric arc welding to
L7	be performed and result in welds which are superior to welds
18	performed by known cored electrode wires using non-pulsed
١9	electric arc welding techniques.
20	The various components of the core of the wire may be
21	modified without detracting from the advantages provided by
22	the present invention. For example, the various alloying
23	components may be modified to suit the required weld metal
24	properties. Similarly, the components of the fused metal
25	oxide used in each core may be modified to suit the user's
26	requirements provided the core contains sufficient easily
27	ionizable material to result in satisfactory improvement of
20	the wold anality

#### 1 CLAIMS:

- 2 1. A cored electrode wire for pulsed electric arc welding,
- 3 characterised in that the slag forming components contained
- 4 in the core of said electrode wire are of a lower level than
- 5 the slag forming components which must be contained in a
- 6 cored wire suitable for normal arc welding.
- 7 2. The electrode wire of claim 1, wherein said core
- 8 includes from 2.5 to 12% calcium fluoride, from 2 to 8%
- 9 calcium carbonate, from 0.2 to 2% silicon dioxide and from
- 10 0.5 to 1.5% of a fused mixed oxide.
- 11 3. The electrode wire of claim 1 or 2, wherein said core
- 12 includes from 2.5 to 8% calcium fluoride, from 2 to 6%
- 13 calcium carbonate, from 0.2 to 1% silicon dioxide and from
- 14 0.75 to 1.25% fused mixed oxide.
- 15 4. The electrode wire of claim 3, wherein said fused mixed
- 16 oxide contains approximately 10% MgO, 15% MnO, 10% Al $_2$ O $_3$ , 5%
- 17 CaO, 60% SiO2.
- 18 5. A cored electrode wire for pulsed electric arc welding,
- 19 in which the wire diameter is from 0.9 to 1.8 mm, and the
- 20 core constitutes from 15 to 28% of the weight of the wire,
- 21 said core have from 3 to 12% elemental manganese, from 2 to
- 22 7% elemental silicon, from 2.5 to 12% calcium fluoride, from
- 23 2 to 8% calcium carbonate, from 0.2 to 2% silicon dioxide,
- 24 from 0.5 to 1.5% fused mixed oxide, from 0 to 1.5% elemental
- 25 chromium, from 0 to 15% nickel, from 0 to 5% molybdenum,
- 26 from 0 to 1.5% titanium, from 0 to 0.045% boron, the
- 27 remainder of the core composition being iron powder.
- 28 6. The electrode wire of claim 5, wherein the core
- 29 comprises from 18 to 25% of the weight of the wire, said core
- 30 comprising from 5 to 9% elemental manganese, from 2 to 5%
- 31 elemental silicon, from 2.5 to 8% calcium fluoride, from 2 to
- 32 6% calcium carbonate, from 0.2 to 1% silicon dioxide, from
- 33 0.75 to 1.25% fused mixed oxide, from 0 to 0.8% titanium, and
- 34 from 0 to 0.033% boron.
- 35 7. The electrode wire of any preceding claim, when used
- 36 with a pulsed electric arc welding apparatus having the
- 37 following welding pulse parameters:

WELLESTITUTE SHEET

- 1 Pulse Energy 8 to 250 J 2 Pulse Frequency 10 to 500 Hz 3 Background Current 8 to 250 A 4 Wire Feed Speed 1 to 20 m/min
- The electrode wire of any preceding claim, when used 5 8.
- 6 with a pulsed electric arc welding apparatus having the
- following welding pulse parameters:
- 8 Pulse Energy 10 to 120 J
- 9 Pulse Frequency 15 to 350 Hz
- 10 Background Current 10 to 100 A
- 11 Wire Feed Speed 4 to 17 m/min
- The electrode wire of claim 7 or 8, wherein the pulse 12
- 13 parameters are:
- 14 Pulse width (ms) 2 to 6 Peak current (A) 15 400 to 550 Minimum Pulse Frequency (Hz) 16 15 to 80
- Maximum Pulse Frequency (Hz) 17 120 to 300 18
- Minimum Background Current (A) 15 to 50 19 Maximum Background Current (A)
- 15 to 80 20 Minimum Wire Speed (m/min)
- 1.56 to 4.55 21 Maximum Wire Speed (m/min) 6.50 to 16.90
- The electrode wire of claim 9, wherein the core 22
- composition of the wire and the pulse parameters used are as 23
- defined in any one of Examples 1 to 4 of the accompanying 24
- 25 specification.
- 11. A cored electrode wire for use with pulsed electric arc 26
- welding, characterised in that the core contains a metal 27
- powder composition having less manganese and silicon than 28
- would be required for a cored wire for use with normal
- 30 electric arc welding.
- 31 The electrode wire of claim 11, wherein said core
- contains from 4 to 15% elemental manganese and from 2 to 8%32
- elemental silicon, the remainder of the core comprising 33
- fused mixed oxide, desired alloying components and iron
- powder. 35
- The electrode wire of claim 12, wherein said core 36
- contains from 6 to 9% f elemental manganese and from 2.5 to 37
- 5% elemental silicon.

- 14. The electrode wire of claim 13, wherein said wire has a 2 diameter of from 0.9 to 1.8 mm and the core comprises from 15 to 25% of the weight of the wire, said core composition 4 comprising from 4 to 12% elemental manganese, from 2 to 8% 5 elemental silicon, from 0 to 1% titanium, from 0 to 1.5% 6 fused mixed oxide, from 0 to 0.05% boron, from 0 to 2% 7 elemental chromium, from 0 to 20% nickel, from 0 to 5%
- molybdenum, the remainder of the core being iron powder.
- 9 The electrode wire of claim 14, wherein said fused
- 10 mixed oxide contains approximately 10% MgO, 15% MnO, 10%
- Al<sub>2</sub>O<sub>3</sub>, 5% CaO, 60% SiO<sub>2</sub>.
- The electrode wire of any one of claims 9 to 13, when 12
- 13 used with a pulsed electric arc welding apparatus having the
- 14 following pulse parameters:
- Pulse Energy 8 to 250 J 15
- 16 Pulse Frequency 10 to 500 Hz
- Background Current 8 to 250 A 17
- 1 to 20 m/min Wire Feed Speed 18
- 17. The electrode wire of any one of claims 9 to 13, when 19
- 20 used with a pulsed electric arc welding apparatus having the
- 21 following pulse parameters:
- 22 Pulse Energy 10 to 120 J
- 23 15 to 350 Hz Pulse Frequency
- 24 Background Current 10 to 100 A
- Wire Feed Speed 4 to 17 m/min 25
- The electrode wire of claim 17, wherein said pulse 26
- 27 parameters are:
- 2 to 6 28 Pulse width (ms)
- 350 to 550 29 Peak current (A)
- 30 Minimum Pulse Frequency (Hz) 25 to 100
- 120 to 350 31 Maximum Pulse Frequency (Hz)
- 10 to 50 32 Minimum Background Current (A) 20 to 100
- Maximum Background Current (A) 33
- 1.26 to 3.78 Minimum Wire Speed (m/min)
- 5.20 to 15.60 35 Maximum Wire Speed (m/min)
- 36 19. The electrode wire of claim 18, wherein said core
- 37 composition and said pulse parameters are as defined in any
- one of Examples 6 to 8 of the accompanying specification.

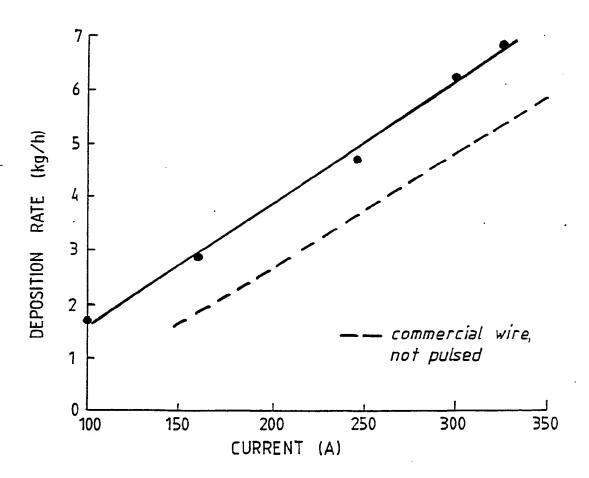


- A method of operating a pulsed electric arc welding 2 apparatus using a cored electrode wire having a basic core 3 composition comprising the steps of adjusting the parameters 4 of the pulse program of the apparatus in accordance with the 5 following: 6 Pulse Energy 8 to 250 J 7 Pulse Frequency 10 to 500 Hz 8 Background Current 8 to 250 A 9 Wire Feed Speed 1 to 20 m/min 21. The method of claim 20, wherein said pulse parameters 10 11 are: 12 Pulse Energy 10 to 120 J 13 Pulse Frequency 15 to 350 Hz 14 Background Current 10 to 100 A 15 Wire Feed Speed 4 to 17 m/min 16 The method of claim 21, wherein said pulse parameters 17 are: 18 Pulse width (ms) 2 to 6 19 Peak current (A) 400 to 550 20 Minimum Pulse Frequency (Hz) 15 to 80 21 Maximum Pulse Frequency (Hz) 120 to 300 22 Minimum Background Current (A) 15 to 50 23 Maximum Background Current (A) 15 to 80 24 Minimum Wire Speed (m/min) 1.56 to 4.55 25 Maximum Wire Speed (m/min) 6.50 to 16.90 23. A method of pulsed electric arc welding utilising a 26 cored electrode wire containing a metallic core, 27 28 characterised in that the electric arc welding apparatus is programmed with the following pulse parameters: 29 30 Pulse Energy 8 to 250 J 31 Pulse Frequency 10 to 500 Hz 32 Background Current 8 to 250 A 33 Wire Feed Speed 1 to 20 m/min 34 24. A method of pulsed electric arc welding utilising a
- 36 characterised in that the electric arc welding apparatus is 37 programmed with the following pulse parameters: 38

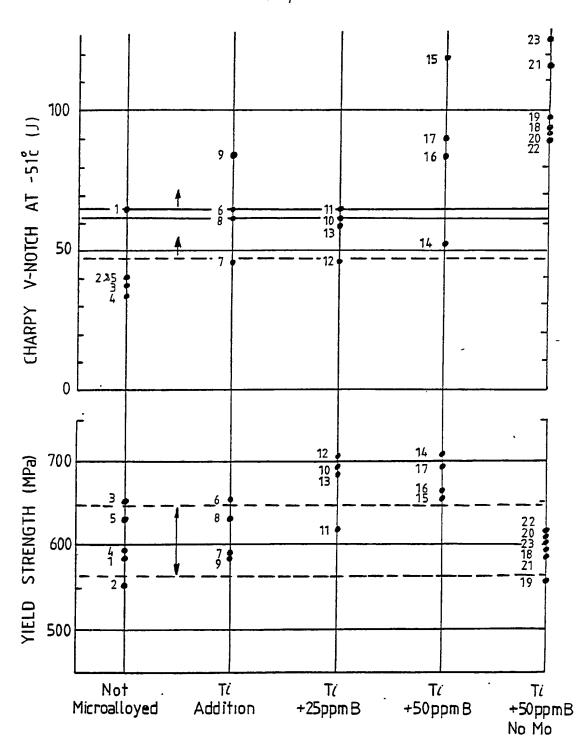
cored electrode wire containing a metallic core,

- 25 -

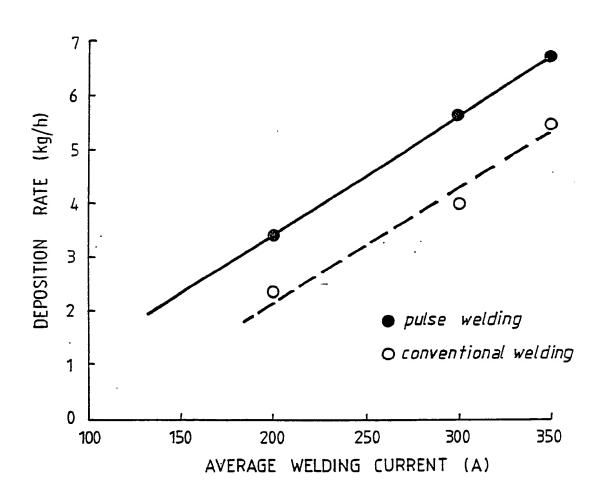
1	Pulse Energy	10 to 120 J	
2	Pulse Frequency	15 to 350 $\mathrm{Hz}$	
3	Background Current	10 to 100 A	
4	Wire Feed Speed	4 to 17 m/min	
5	25. A method of pu	lsed electric arc welding	utilising a
6	cored electrode	wire containing a met	allic core,
7	characterised in th	at the electric arc welding	g apparatus is
8	programmed with the	following pulse parameters	•
9	Pulse width (ms)		2 to 6
9 10	Pulse width (ms) Peak current (A)		2 to 6 350 to 550
	•	ency (Hz)	
10	Peak current (A)	· ·	350 to 550
10 11	Peak current (A) Minimum Pulse Freque	ency (Hz)	350 to 550 25 to 100
10 11 12	Peak current (A) Minimum Pulse Freque Maximum Pulse Freque	ency (Hz) Current (A)	350 to 550 25 to 100 120 to 350
10 11 12 13	Peak current (A) Minimum Pulse Freque Maximum Pulse Freque Minimum Background (	ency (Hz) Current (A) Current (A)	350 to 550 25 to 100 120 to 350 10 to 50



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顶。2.



顶. 3.

## INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 89/00045

1. CLASSIFICATION OF SUBJECT MATTER (il several classification symbols apply, indicate ell) 4					
According to International Patent Classification (IPC) or to both National Classification and IPC					
Int. C1.4 B23K 35/30, 35/368, 9/09					
II. FIELDS	5 SEARCHED				
	Minimum Documentation Searched ?				
Classification	on System Classification Symbols				
IP					
US	C1. 219/146.52				
	Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included In the Fields Searched *				
AU : IPC as above, Australian Classification 06.9					
III. DOCU	MENTS CONSIDERED TO BE RELEVANT				
Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13			
X	US,A, 3825721 (CARROLL et al) 23 July 1974 (23.07.74)	(1)			
х	US,A, 3787658 (KAMMER et al) 22 January 1974 (22.01.74)	(1,11)			
х	US,A, 3702390 (BLAKE et al) 7 November 1972 (07.11.72)	(1-3,11)			
х	US,A, 3643061 (DUTTERA et al) 15 February 1972 (15.02.72)	(1,11)			
χ.	US,A, 3504160 (ESSERS et al) 31 March 1970 (31.03.70)	(1,11)			
х	Derwent Abstracts Accession No. 83-791687/42 Class P55, JP,A, 58-151993 (NIPPON OILS & FATS KK) 9 September 1983 (09.09.83)	(1-3)			
х	AU,B, 17265/70 (439774) (MUREX WELDING PROCESSES LIMITED) 27 August 1973 (27.08.73)	(1,2,11)			
х	DE,A1, 3320513 (ESAB AB) 7 June 1983 (07.06.83)	(11,12) -			
		:			
	*				
		<u>                                     </u>			
* Special categories of clied documents: 10  "T" later document published after the International filling date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the					
considered to be of particular relevance invention  "E" earlier document but published on or after the International "A" document of particular relevance; the claimed invention filing date cannot be considered novel or cannot be considered to					
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another of particular relevance; the claimed invention citation or other special reason (as specified)					
"O" doce	"O" document referring to an oral disclosure, use, exhibition or other means  One other means  One of the international filling data but				
later than the priority date claimed "4" document member of the same patent family					
IV. CERTIFICATION					
Date of the Actual Completion of the International Search  15 May 1989 (15.05.89)  Date of Mailing of this International Search Report  24 May 1989 (24.05.89)					
Australian Patent Office  Signature of Authority  W.J. MAJOR					
		<del></del>			

Form PCT/ISA/210 (second sheet) (January 1985)

FURTHER INFORMATI N

## VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING (contd)

This International Searching Authority found multiple inventions in this International application as follows:

Claims 1,11 and 20 relate to different aspects of welding with no common unifying feature.

Claim 1 is directed to the slag forming content of a welding electrode.

Claim 11 is directed to the components of a welding electrode relevant to weld bead formation.

Claim 20 is directed to a pulsed arc welding process using any welding electrode.

These aspects are entirely independent and require separate searches.

Form PCT/ISA/ZID (supplemental sheet (1)) (October 1981)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET				
1				
V. BSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE				
This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:				
1. Claim numbers because they relate to subject matter not required to be searched by this Authority, namely:				
•				
•				
the description of the second with the prescribed femilies				
2. Claim numbers, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:				
ments to such an extent that no treatment of the such as the such				
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hosping they are dependent claims and are not drafted in accordance with the second and third sentences of				
3. Claim numbers because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).				
PCT Rule 6.4(a).				
PCT Rule 6.4(a).  VI. X OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2				
PCT Rule 6.4(a).				
PCT Rule 6.4(s).  VI.X OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This International Searching Authority found multiple inventions in this international application as follows:				
PCT Rule 6.4(a).  VI. X OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2				
PCT Rule 6.4(s).  VI.X OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This International Searching Authority found multiple inventions in this international application as follows:				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This International Searching Authority found multiple inventions in this international application as follows:  See attached Sheet				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the International application.				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This International Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.  2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the International application for which fees were paid, specifically claims:				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.  2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:				
PCT Rule 6.4(a).  VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.				
PCT Rule 6.4(a).  VI.X OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING?  This International Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.  2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:  3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:  1 to 10				
VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING?  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.  2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:  3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:  1 to 10				
PCT Rule 6.4(s).  VI. DBSERVATIONS WHERE UNITY OF INVENTION IS LACKING?  This International Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.  2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:  3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:  1 to 10				
VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING?  This international Searching Authority found multiple inventions in this international application as follows:  See attached Sheet  1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.  2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:  3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:  1 to 10				

Form PCT/ISA/210 (supplemental sheet (2)) (January 1985)

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